Artificial Neural Network based Speed Control of Bidirectional Chopper fed Induction Motor Drive using DFRT Theory

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Abstract - In this paper, a new simulink model for a single phase induction motor is proposed using double field revolving theory. To maintain a constant fluid flow with a variation in the pressure head, drives like Fan load and Pump load are operated with closed loop speed control. For non linear loads, closed loop speed control is achieved using a neural network controller. A comparative study has been made between the conventional and neural network controllers. It is observed that the neural network controlled drive system has better dynamic performance, reduced overshoot and faster transient response than the PI controlled system.

Keywords - Pulse width modulation, double field Rrevolving theory, induction motor modeling, total harmonic Distortion, neural network controller.

Abbreviations

PWM	*Pulse Width Modulation*
AC	*Alternating current*
SCR	*Silicon Controlled Rectifier*
HP	*Horse Power*
DFRT	*Double Field Revolving Theory*
NN	*Neural Network*

Nomenclature

s	*Slip*
R_1	*Stator resistance in ohms*
R_2	*Rotor resistance referred to stator in ohms*
R_0	*Equivalent resistance corresponding to the iron losses in ohms*
L_1	*Leakage inductance of Stator in henry*
L_2	*Leakage inductance of Rotor referred to stator in henry*
L_0	*Magnetizing inductance of the stator in henry*
X_1	*Leakage reactance of Stator in ohms*
X_2	*Leakage reactance of Rotor referred to stator in ohms*
X_0	*Magnetizing reactance of the stator in ohms*
V_i	*Input voltage in volts*
V_0	*Output voltage in volts*
V_1	*Voltage across the variable rotor resistance in volts*
V_f	*Output voltage due to forward field in volts*
V_b	*Output voltage due to backward field in volts*
V_0	*Output voltage*
I	*Current flowing through the stator in Amps*
I_1	*Iron-loss and magnetizing component of the no-load current in Amps due to forward field*
I_2	*Rotor current referred to the stator in Amps due to forward field*
I_3	*Iron-loss and magnetizing component of the no-load current in Amps due to backward field*
I_4	*Rotor current referred to the stator in Amps due to backward field*
P_{gf}	*Airgap power developed by the motor due to forward field*
P_{gb}	*Airgap power developed by the motor due to backward field*
T	*Torque developed by the motor in Nm*
T_L	*Load Torque in Nm*
n_s	*Synchronous speed in rps*
J	*Moment of inertia in Kgm^2*
B	*Viscous friction in Nms*
P	*Number of Poles*
ω	*Angular speed in rad/sec*
θ	*Angular displacement in radians*
Y	*Output vector of the hidden layer*
O	*Output vector of the output layer*
V_{ji}	*weight matrix*
W_{kj}	*weight matrix*
B_1	*Bias vector*
B_2	*Bias vector*
X	*Input*
$a(.)$	*Activation function*
Z_j	*Activation of node j*
μ_j	*Threshold of the node j*

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I. INTRODUCTION

The single-phase induction motor plays an important role in the life of industries. The advantages of this motor over other types of motor are, its simplicity, reduced cost, low maintenance and robustness. Although induction machines are the cheapest and most reliable, their controller is complex and most expensive. Due to the growing demand in improving the performance of motor drives, there is an increasing need to improve the quality and reliability of the drive circuit. The AC voltage regulator is used as one of the power electronic systems to control an output AC voltage for power ranges from a few watts up to fractions of megawatts. Phase-angle control of line-commutated voltage controllers and integral-cycle control of thyristors have been traditionally used in these types of regulators. Some techniques offer advantages such as simplicity and the ability of controlling a large amount of power economically. However, they suffer from inherent disadvantages, such as retardation of the firing angle, causing a lagging power factor at the input side, in particular, at large firing angles, and high low-order harmonic contents in both load and supply voltages/currents. AC-to-AC converter schemes using pulse width modulation (PWM) are proved to achieve substantial advantages over conventional line-commutated AC controllers. (Sadeq A. Hamed 1990, Lautaro Salazar 1993, N.A.Ahmed 1999 and M. Lucanu 2003).

An optimal control strategy can be applied for selecting firing and commutation angles in pulse-width-modulated AC/AC chopper to eliminate selected harmonics in single-phase converters (D.A.Deib 1993, K.E.Addoweesh 1990, Yu Hongxiang 2004 and A.N.Arvindan 2006). M.J.Meco-Gutierrez (2007) has described an alternative technique, which involves the same number of commutations per unit time and therefore causes the same amount of heating in the transistors, while generating an output signal with an appreciable increase in the fundamental term and a significant reduction in lower order harmonics, which are most difficult to filter.

The double field revolving theory is effectively used to obtain the model of single induction motor. When the two fields are known the torque produced by each field can be obtained. The difference between these two is the net torque acting on the rotor. As most of the drives require constant speed operation, the firing angle is changed to maintain constant speed. The speed control in closed loop system is implemented using neural network controllers.
For controlling the speed of a single-phase induction motor, a chopper circuit is employed in the stator side (A.M. Makky 1995). The chopping switch is placed across a diode rectifier bridge, which terminates the stator winding from the opposite side to the supply. By changing the chopping frequency the rotor speed changes. The ratio of the voltage to frequency can be kept constant by using phase control in addition to the frequency control. However, remarkable speed ripples accompany low chopping frequencies. Microcontroller is used to control the speed of symmetrical pulse width modulated AC chopper fed single phase induction motor with reduced speed ripple (N.A.Ahmed 2000, S.H.Hamad 2004 and S.M.Bashi 2005). The microcontroller senses the speed's feedback signal and consequently provides the pulse width variation signal that sets the gate voltage of the chopper, which in turn provides the required voltage for the desired speed.

As long as the parameters of PID control, proportional gain, integral time, differential time and sampling period are optimized and tuned, conventional PID control obtains better performance and higher control precision. However, the robustness of PID is reduced when the parameters of the model are varied. The neural network PID control, which is a method for adaptively adjusting the PID gains using backpropagation algorithm can be adopted. The neural network PID control has the capability of self-study and self-adaptation (Y.S.Kung 1995 and Jiangjiang Wang 2007).

A control technique based on a neural network is proposed here for the constant speed control of the single phase induction motor drive. In the industry, the PI controller is widely used. These controllers exhibit excellent ability if a simple control is to be implemented. However, they have low reliability because these control results are sensitive to change in system parameters and do not react rapidly to parameter changes. Also, these controllers show a higher maximum overshoot and longer settling time. To solve these problems, a neural network that adjusts itself to control circumstances, is used.

Various kinds of neural network architecture is studied (B.K. Bose 2001). Most of the current ANN applications are restricted to feed forward back propagation type network. Off-line trained artificial neural networks are applied for creating the system inverse models that are used at designing control algorithm for non-linear dynamic system (O.Bouhali 2005 and Jaroslava Zilkova 2006). Backpropagation neural networks find application in a self-tuning adaptive control of unknown, non-linear and feedback linearizable plants. (Kulawaki G. J.1994)
The above literatures does not deal with neural network based closed loop control of bidirectional chopper fed induction motor drive systems. In the present work, the simulation has been performed for both phase controlled and pulse width modulated chopper systems. From the simulation, it is proved that the performance of pulse width modulated AC chopper system is superior to phase controlled AC chopper system. A new simulink model of single phase induction motor using double field revolving theory is proposed. Artificial neural network based closed loop speed control is proposed for the single phase induction motor.

II. Bidirectional Chopper Fed Induction Motor

A block diagrammatic representation of a neural network controlled AC chopper fed single phase induction motor is shown in Fig. 1. The circuit can operate directly from a single phase line and the voltage across each switch is limited to the line voltage. Various parameters, namely, pulse width modulated voltage, stator current, speed of the induction motor and error in speed are sensed and given to the neural network. It generates the driving pulses to the switches in order to maintain the speed of the machine at reference value. A neural network is proposed for speed regulation. During each time, the weights and biases of the neural network are updated using the back propagation algorithm to make the error between the desired outputs and actual outputs of the neural network less than the predefined value.

The neural network controller has a 6-3-1 structure. This neural network structure is the result of many repeated trials. For each load, the training data is obtained by tuning the PI controller parameters such as $k_{p,}$ k_i to optimal values in order to obtain a small steady-state error.

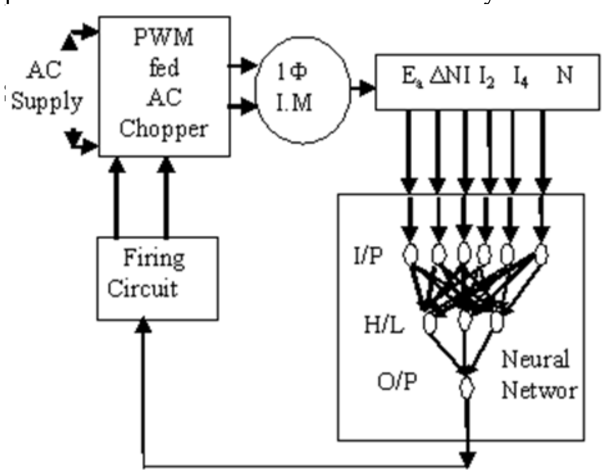

Fig. 1: Block diagram of single phase induction motor with neural network controller

The neural network controller is capable of maintaining a good steady-state and dynamic responses, and shows a significant improvement in reducing the distortion of the output voltage under non-linear loading conditions. It is suitable for the applications where the load undergoes periodic distortions.

III. Simulink Model of Single Phase Induction Motor

The equivalent circuit of the single phase induction motor is considered to derive the simulink model of it. Since the value of slip (s), is generally small, $R_2/2s$ is considerably higher than $R_2/[2*(2\text{-}s)]$. In general, the magnitude of V_f (V_0-V_b) is 90% to 95% of the applied voltage.

Current flowing through the stator is expressed as

$$I(s) = \frac{(V_i(s) - V_0(s))}{(R_1 + sL_1)} \quad (1)$$

A. Model for Forward Field

Current flowing through the stator can be expressed as

$$I(s) = I_1(s) + I_2(s) \quad (2)$$

If the rotor current referred to the stator is taken as I_2, then the iron-loss and magnetizing component of the no-load current can be expressed as

$$I_1(s) = I(s) - I_2(s) \quad (3)$$

The forward field voltage can be obtained from the expression

$$V_f(s) = V_0(s) - V_b(s)$$

$$= \{I_1(s)\}\left\{\frac{sR_0L_0}{(R_0 + sL_0)}\right\} \quad (4)$$

It can be rewritten as

$$V_f(s) = V_0(s) - V_b(s) \quad (5)$$

$$= \{I_1(s)\}\left\{R_0 - \left[\frac{R_0^{\,2}}{(R_0 + sL_0)}\right]\right\}$$

Voltage across the rotor inductance is expressed as

$$V_1(s) = \{V_f(s) - I_2(s)\}\left(\frac{R_2}{s}\right) \quad (6)$$

The rotor current referred to stator can be expressed as

$$I_2(s) = \frac{\lfloor V_f(s) - V_1(s) \rfloor}{sL_2} \quad (7)$$

Airgap power developed by the motor is given by the expression

$$P_{gf}(s) = \{[I_2(s)]^2\}\{\frac{R_2}{s}\} \quad (8)$$

A. Model for Backward Field

Current flowing through the stator can be expressed as

$$I(s) = I_3(s) + I_4(s) \quad (9)$$

If the rotor current referred to the stator is taken as I_4, then the iron-loss and magnetizing component of the no-load current can be expressed as

$$I_3(s) = I(s) - I_4(s) \quad (10)$$

The forward field voltage can be obtained from the expression

$$V_b(s) = \{I_3(s)\}\left\{\frac{sR_0L_0}{(R_0 + sL_0)}\right\} \quad (11)$$

It can be rewritten as

$$V_b(s) = \{I_3(s)\}\left\{R_0 - \left[\frac{R_0^{\,2}}{(R_0 + sL_0)}\right]\right\} \quad (12)$$

Voltage across the rotor inductance is expressed as

$$\{V_b(s) - I_4(s)\}\left(\frac{R_2}{(2-s)}\right) \quad (13)$$

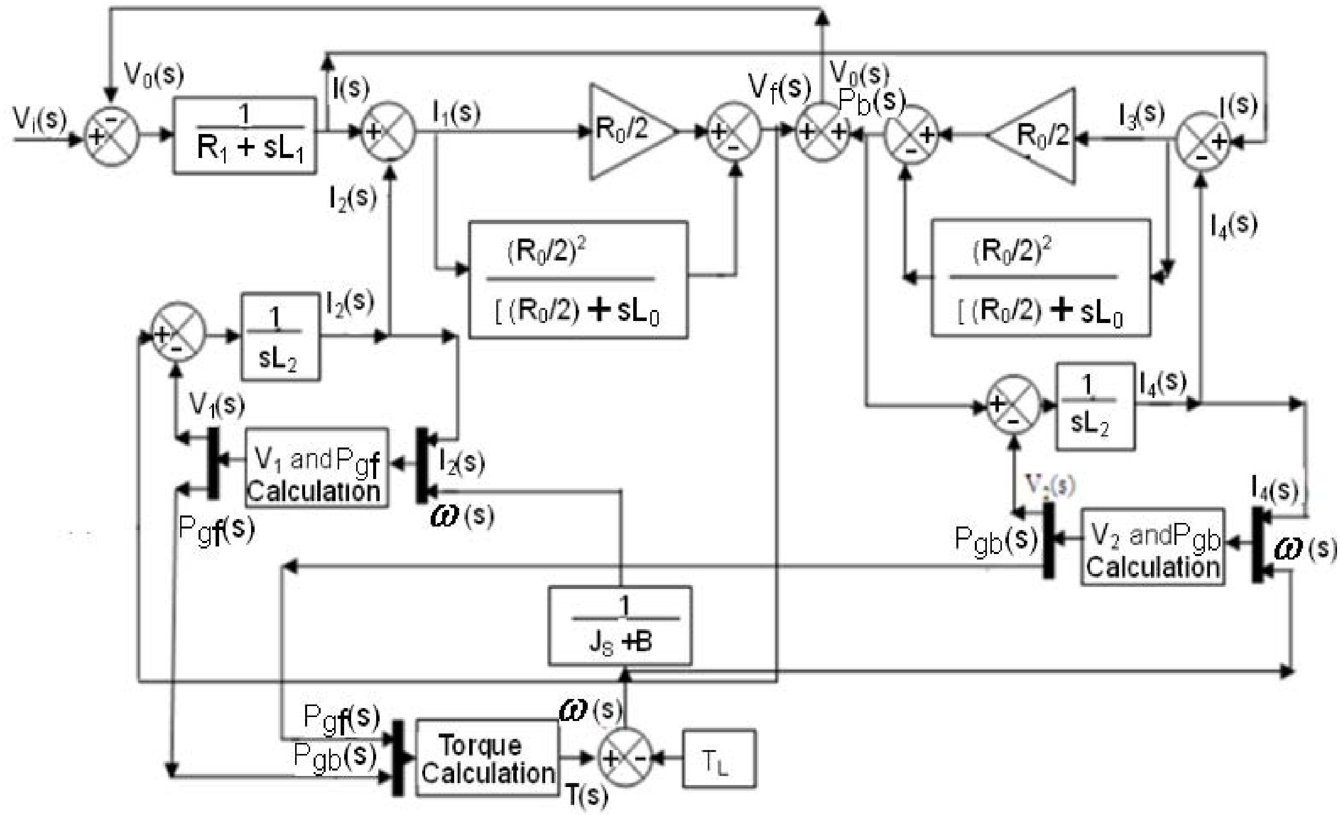

Fig. 2: Simulink model of single phase induction motor using DFRT

The rotor current referred to stator can be expressed as

$$I_4(s) = \frac{[V_b(s) - V_2(s)]}{sL_2} \quad (14)$$

Airgap power developed by the motor is given by the expression

$$P_{gb}(s) = \{[I_4(s)]^2\}\{\frac{R_2}{(2-s)}\} \quad (15)$$

Torque developed by the motor is given by the expression

$$T(s) = \frac{P_{gf}(s) - P_{gb}(s)}{2\pi n_s} \quad (16)$$

The load balance equation is given by

$$\omega(s) = \frac{(T(s) - T_L(s))}{Js + B} \quad (17)$$

From (1) – (17), the model for the single phase induction motor is obtained. The proposed model is shown in Fig. 2. A 1 HP, 230V Single phase induction motor with the following parameters is used for simulation.

R_1=3.4Ω	X_1=3.45Ω	R_2=1.6Ω
X_2=3.45Ω	R_0=170.58Ω	X_0=76.44Ω
J=0.0146kgm^2	B=0.00365Nms	

IV. Neural Network Controller

Neural networks are simply a class of mathematical algorithms, since a network can be regarded as a graphic notation for a large class of algorithms. The hidden layer transfer function is log-sigmoid or tan-sigmoid and the output transfer function is usually linear. Here, the tan-sigmoid is used as the hidden layer transfer function followed by the linear transfer function for the output layer. The neural network system to estimate the duty ratio of AC chopper fed single phase Induction Motor is shown in Fig. 3.

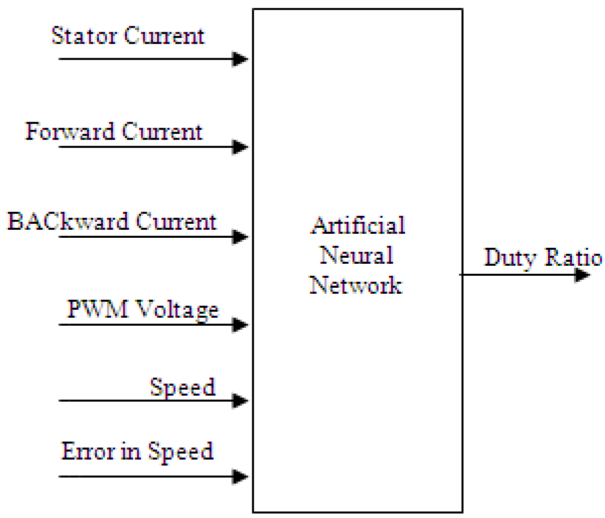

Fig. 3: Neural Network system to estimate duty ratio of PWM AC Chopper fed Single Phase Induction Motor

Output of each hidden node j is given in (18).

$$Y_j = a(Z_j) \quad (18)$$

Where a(.) is termed the activation function and the expression for Z_j is given in (19).

$$Z_j = \sum_i V_{ji} X_i + \mu_j \quad (19)$$

is termed the activation of node j and it is the weighted sum of the inputs X_i to that node and μ_j is termed the threshold of the node. The most commonly used activation function is the sigmoid function and given in (20).

$$a(Z) = 1 / (1 + e^{-z}) \quad (20)$$

The output of each output node is linear and is given in (21).

$$O_k = \sum_j W_{kj} Y_j \quad (21)$$

Where V_{ji} and W_{kj} are weights of hidden and output layers.

Equations 22 and 23 show the transfer functions, where X is the input vector, Y and O are the output vectors of the hidden layer and output layer respectively. V_{ji}, W_{kj} are the weight matrices, and B_1 and B_2 are the bias vectors.

$$Y = 1 / (1 + e^{-(V_{ji}.X + B_1)}) \quad (22)$$

$$O = (W_{kj})(Y) + B_2 \quad (23)$$

To provide the required data to train the neural network, a simulation program is written to obtain the duty ratio values for different load torques. Using this programme, 1,00,000 sets of training pattern such as pulse width modulated output voltage, stator current, speed of the machine, load torque and duty ratio values are obtained. These patterns are used for training the neural network using error back propagation algorithm. After training the neural network successfully, the program is replaced by neural network controller and the simulation has been performed. Output of the neural network controller is used to vary the duty ratio of the PWM AC chopper.

V. Closed Loop Stator Voltage Controlled Single Phase Induction Motor

The neural network based closed loop stator voltage control of a single phase induction motor system is shown in Fig. 4. The power circuit used to generate the Pulse Width Modulated AC voltage is modeled and simulated. PWM AC voltage is applied to the single phase induction motor and the speed is sensed by using a speed sensor. The actual speed of the motor is compared with the reference speed, which can be set by the industrial user according to his requirement. The error in speed is given to the PI controller with a saturator. Initially, PI controllers are used to control the voltage applied to the single phase induction motor. The values of k_P and k_I are tuned for various load conditions. For each load, the PI controller is tuned to obtain a constant speed, and parameters like pulse width modulated output voltage, stator current, speed of the machine, error in speed and duty ratio are estimated. Around 1,00,000 sets of training patterns are obtained. These patterns are used for training the neural network, using the error back propagation algorithm. The internal structure of the trained neural-network used for the simulation is shown in Fig. 5.

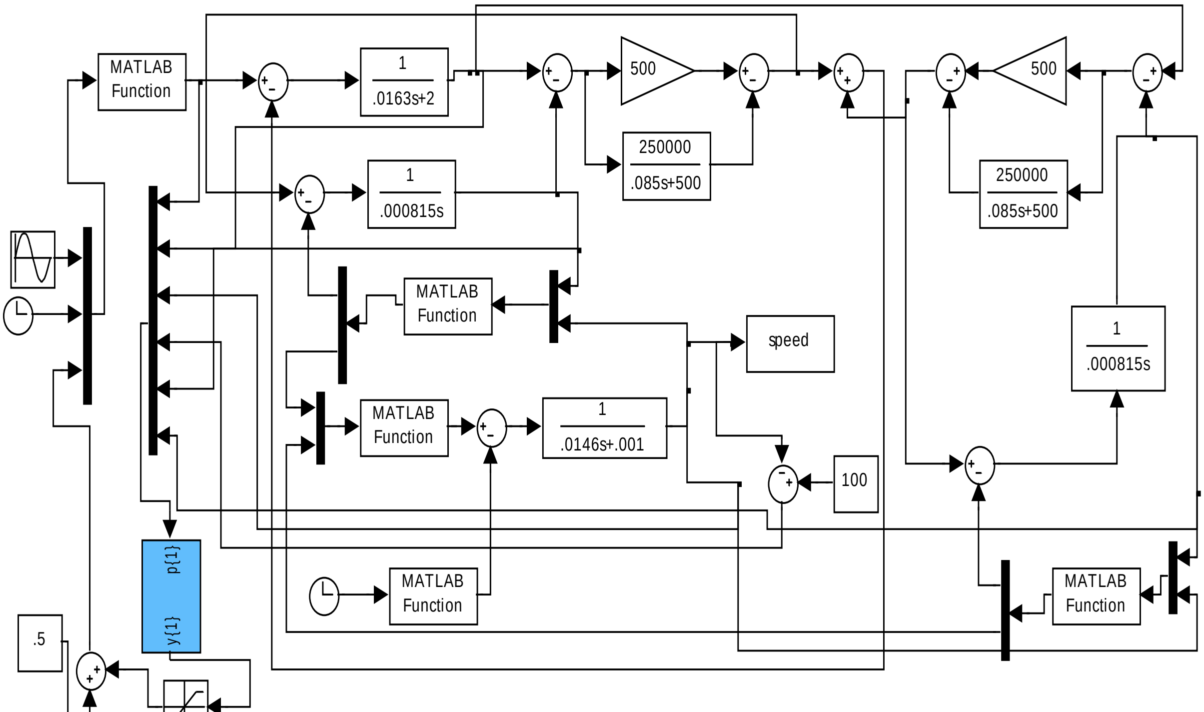

Fig. 4: Model of neural network based Bidirectional chopper fed induction motor

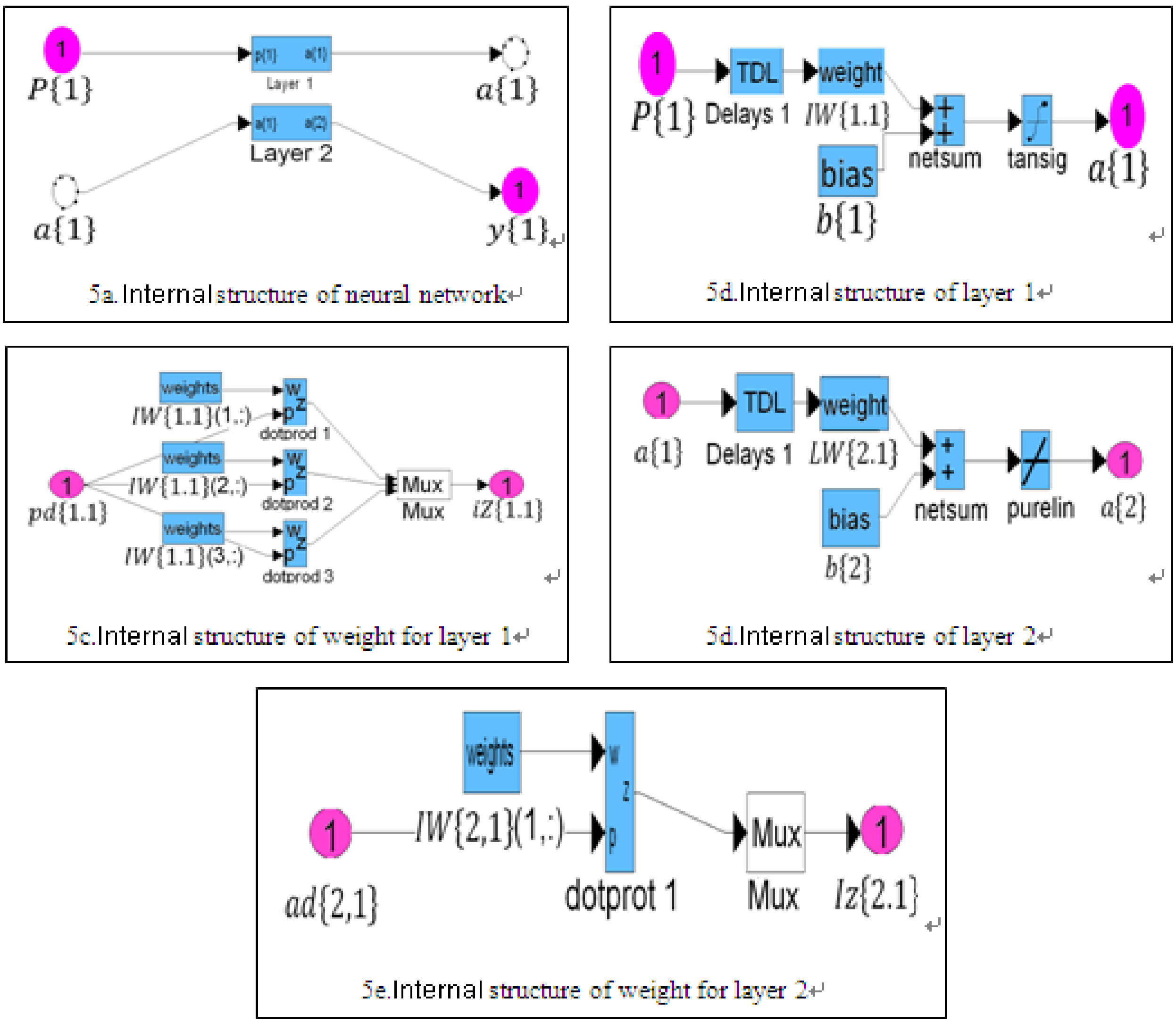

Fig. 5: Internal structure of the trained neural-network

After training the neural network successfully, the conventional PI controller is replaced by the neural network controller and the simulation is performed. The output of the neural network controller is used to vary the duty ratio of the PWM AC chopper. Non-linear exponential load is considered. The speed response for the open loop system from no load to maximum load torque is shown in Fig. 6. From Fig. 6, it can be seen that the speed

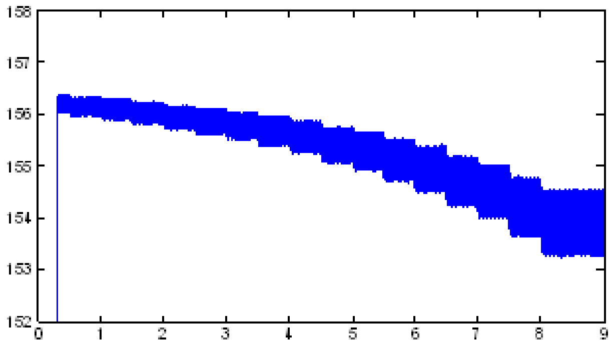

Fig. 6: Speed response with open loop system

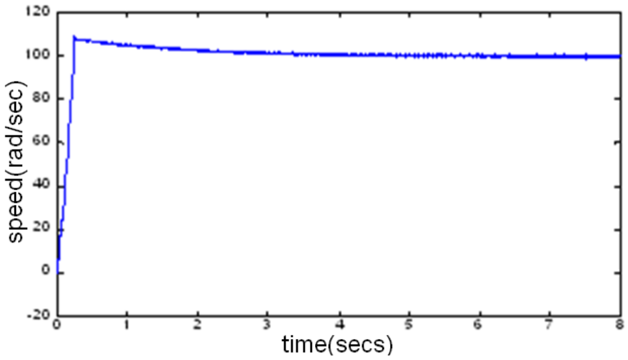

Fig. 7: Speed response with PI controller

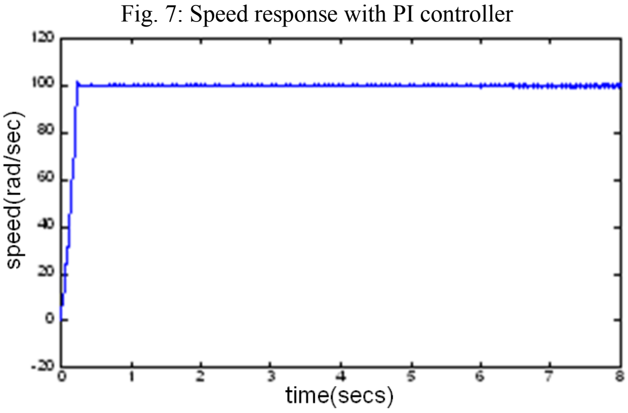

Fig. 8: Speed response with neural network

is not constant in the open loop system. The speed at no load is 156.4rad/sec. As the load is increased, the speed decreases, and finally, it reaches 153.2rad/sec for full load. The speed is maintained at reference value irrespective of the load torque with a closed loop stator voltage control. The speed is maintained constant as shown in Figs. 7 and 8 for non-linear variation of load torque. The simulation is carried out for a reference speed of 100 rad/sec. The speed is maintained at 100rad/sec using PI and NN controllers. The steady state error is reduced. Thus, the closed loop system is capable of maintaining the speed at constant value. The simulation results obtained by using the neural network and PI controllers are given in Table 1.

Table 1: Comparison of Neural Network and PI Controller based Induction Motor Drive systems

Parameters	Neural Network	PI Controller
Rise time(sec)	0.2	0.274
Settling time(sec)	0.2636	4
Peak Overshoot(%Mp)	1.9608	9.091

From the above table, it can be seen that the neural network has lesser peak overshoot, reduced rise and settling time.

VI. CONCLUSION

The Pulse Width Modulated AC Chopper and the Phase Angle Controlled AC Chopper fed Induction motor systems are simulated and their performances are compared. It is proved that the Pulse Width Modulated AC Chopper has lesser total harmonic distortion, better power factor and negligible harmonic components.

Modeling of an Induction Motor has been done using double field revolving theory and the closed loop control has been analyzed. An intelligent control system using a neural network controller has reduced peak overshoot, rise time and settling time compared to the system with a PI controller. It is observed that the speed of the machine remains constant with reduced overshoot by using the neural network-based controller.

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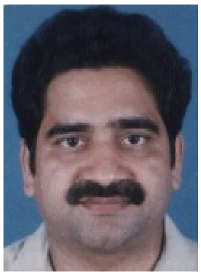

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